

## Characteristics and dynamics of sandy natural forests in sandy forest-steppe ecotone in the northern area of China

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**Abstract:** The research was carried out on sandy natural forest ecosystems in sandy forest-steppe ecotone in the northern area of China from 1980's. In this paper, we introduced the concept and origin, distribution and actuality, types and succession of sandy natural forests in the northern area of China. The conservation value and strategy for sandy natural forests were also discussed. We hope to supply some scientific basis for performing "the Natural Forest Protection Program" reasonably in China.

**Key words:** Sandy natural forests, Sandy forest-steppe ecotone, China

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### Introduction

Violent human disturbance results in global landscape and vegetation fragmentation, including the polar landscape and alpine vegetation (Cox, 1993). In modern world, environment and development are two important problems, which have a direct effect on the destiny of human and the earth. Forestry, which undertakes double missions that are to optimize the environment and promote the development, is the crux to realize the unity of environment and development (Liu 1985).

China is a developing country with large population and poor forest resources. What's more, the enormous population causes a grave pressure on the forestry. Therefore, a series of important political, economic, and legal steps have been put into practice and have promoted the development of forestry construction. At the same time, "the Natural Forest Protection Program" was carried out from 1998. Sandy natural forests (SNF) are very valuable forest resource in China, which distribute mainly in semi-moisture and semi-arid sandy forest-steppe ecotone. In the northern area of China, SNF elaborate enormous ecological benefit, economical benefit, and social benefit for controlling desertification, establishment of "Three North Protection Forest", and

improving environment quality of local people. Therefore, researches on SNF have significant scientific purport and practical value. It is an urgent assignment to develop research on SNF. We were honor to be funded by Chinese Academy of Sciences and National Nature Science Foundation of China to study on SNF from 1980's.

### Sandy natural forests (SNF) in China

What is SNF? It may be not defined in modern forest ecology yet. We thought that SNF are the forest communities, which distribute at the sandy land in steppe zone in China. They don't include *Populus euphratica* forest in desertion steppe zone, Maomusu Sandy Land, and *Haloxylon ammodendron* forest in desert zone, Talimu River Bank. SNF mainly refer to coniferous forest and broad-leaved forest which edificators are large or middle phaenophytes (Xu and Zou 1998; Xu *et al.* 1998).

There are three pieces of SNF in sandy forest-steppe ecotone in the northern area of China.

The first piece is Hulunbeier Sandy Land, which locates at the transitional zone from meadow in western slope of Daxing'an Mountains to typical steppe. Sand layer is more than 50 ms thick. Sandy *Pinus sylvestris* var. *mongolica* forest (SPSMF) distributes extensively in the shade slope of dunes, and the area is about 8 866 hm<sup>2</sup>, mean tree height is 14 m, mean DBH is 20 cm, and canopy close degree is 0.4-0.7. In the down part of dunes, there is sandy *Populus davidiana* forest (SPDF) and sandy *Betula platyphylla* forest (SBPF). In the sunny slope of dunes, the vegetation is steppe.

The second piece is Keerqin Sandy Land, which locates at transitional zone from Daxin'an Mountains

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to Jibei Mountains. Sandy *Ulmus pumila* sparse forest (SUPSF) distributes in the top of the dunes, but in shade slope of dunes, there is sandy *Quercus mongolica* forest (SQMF). In Songshushan Mountains of Keerqin Sandy Land, there exists sandy *Pinus tabulaeformis* forest (SPTF). Its distribution area is about 200  $\text{hm}^2$ . The tree age averages 30-50 years and canopy close degree is 0.3-0.4. In Daqinggou Natural Reserve, there are sandy broad-leaved forest (SBLF) and SQMF, sandy *Fraxinus mandshurica* forest (SFMF), and SUPSF.

The third piece is Hunshandake Sandy Land, which locates at district between Daxing'an Mountains and Jining-Erlianhaote Railway. It is 340 km from west to east, 50-100 km from south to north, and altitude is 1100-1300 m. In Huanggangliang Mountains, Dajuzi, and Dalinuoer, there are some remnant SPTF, and here is the northern distribution border of *Pinus tabulaeformis*. In Baiyinaobao Natural Reserve, there are 1790  $\text{hm}^2$  primary sandy *Picea mongolica* forest (SPMF), and mixed with SPDF and SBPF, and sandy herb-grass-steppe. SUPSF extensively distributes in Hunshandake Sandy Land, and forms complex landscape with *Artemisia intramongolica*, and so on.

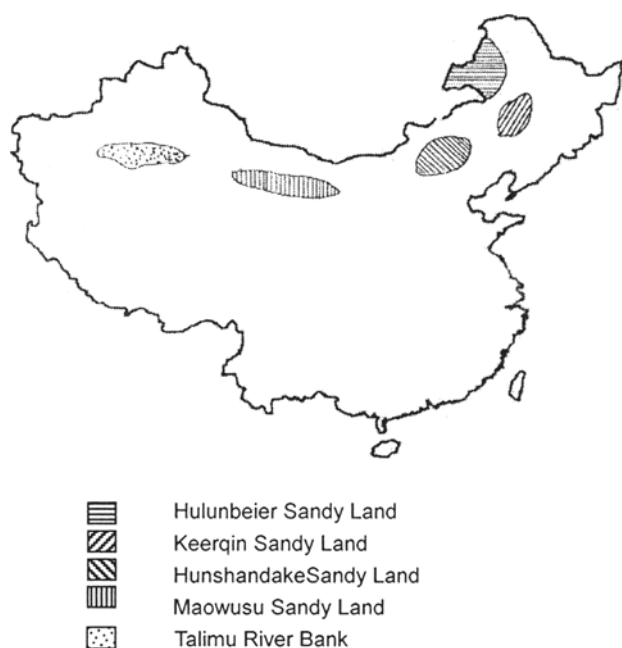


Fig. 1. Distribution of SNF in China

We introduced "super zonal climax" in order to explain the nature of SNF. Super zonal climax is different with non-zonal climax. Zonal climax is controlled by zonal climate. Moreover, in one climate zone, there is only one zonal climax. Non-zonal climax is topical distribution pattern in horizontal direction,

such as swamp (Liu 1985). There are multiply climatic factors, and moisture-temperature conditions are very important. The factor limiting distribution of montane natural forest is temperature, but the factor limiting origin and development of SNF is water or moisture. According to Xu's humidity index (HI), SNF only distribute in the place where HI range is 7.5-3.5  $\text{mm}/^{\circ}\text{C} \cdot \text{month}$ , but montane natural forest distributes in the place where  $\text{HI} > 7.5 \text{ mm}/^{\circ}\text{C} \cdot \text{month}$ . In the place where  $\text{HI} < 3.5 \text{ mm}/^{\circ}\text{C} \cdot \text{month}$ , the forest can not form naturally (Xu 1993). Therefore, SNF are result of long-term vegetation history and modern natural conditions. Their formation, development, and distribution are controlled by zonal climate, and they are coincident with fixation process of sandy matrix. The uniform characteristic of sandy forest ecosystems is that they have obvious phases, and zonal brand.

Then, what connection do SNF have with montane natural forest and steppe?

Firstly, as far as origin and historical succession is concerned, sandy *Pinus sylvestris* var. *mongolica* is a variant of *Pinus sylvestris*, but montane *Pinus sylvestris* var. *sylvestris* is original variant of *Pinus sylvestris*. *Pinus sylvestris*, which almost distributes in the whole Europe-Asia continent, is one of the extensively distributive species. According to precious research, *Pinus sylvestris* was forced to move to southeastern direction through Siberia in glacial period, and moved to the western part of Hulunbeier County, Inner Mongolia Autonomous Region, Daxing'an Mountains, and Xiaoxing'an Mountains, to the northern slope of Changbai Mountain. However, in interglacial period, *Pinus sylvestris* retreated and formed discontinuous distribution. The species *Pinus sylvestris* which entered Daxing'an Mountains formed montane *Pinus sylvestris* var. *sylvestris* forest, while those that distributed in Hulunbeier Sandy Land formed SPSMF. In Daqinggou Natural Reserve, *Quercus mongolica*, *Fraxinus mandshurica*, *Phellodendron amurense*, and *Juglans mandshurica* are remnant discontinuous zonal climax coming from Changbai Mountains, so it is post-climax. Steppe around Daqinggou Natural Reserve is zonal climax. The vegetation obviously is forest-steppe landscape. SPMF is a variant of montane *Picea meyeri* forest, and it also is remnant vegetation. SPMF is super zonal climax. *Picea mongolica* has evolved into a new species through adaptation to its environment for thousands of years, and formed super zonal climax vegetation in zonal steppe. Moreover, SPTF is remnant vegetation, too. *Pinus tabulaeformis* has powerful adaptability, and forms many new species, for example, *Pinus jeholensis*. SPDF and SBPF are secondary SNF, which HI is more than 5.5  $\text{mm}/^{\circ}\text{C} \cdot \text{month}$ . If  $\text{HI} < 15.5 \text{ mm}/^{\circ}\text{C} \cdot \text{month}$ , the

vegetation will be SUPSF, which is also a post-climax.

Secondly, as to community characteristics of SNF, they have dualism of forest and steppe. Generally speaking, upper layer of community is large or middle phaenerophytes synusia, but they possess forest appearance characteristics. For example, SPSMF has characteristics of Taiga forest, SPMF has characteristics of dark coniferous forest, and SPTF has characteristic of warm temperate coniferous-deciduous forest. The middle layer of community is xeric-mesic, or mesic-xeric, or xeric low phaenerophytes synusia, such as *Ostrgopsis davidiana* plant synusia, *Cotoneaster melanocarpus* plant synusia, *Caragana mictophylla* plant synusia, and so on. In down layer, steppe compositions take up certain proportion, such as *Stipa baicalensis*, *Koeleria cristata*, *Aneurolepidium chinense*, *Filifolium sibiricum*, *Iris tenuifolia*, *Potenitilla acaulis*, and so on, about more than 50 species. Combination of forest and steppe forms a sandy forest-steppe ecotone landscape.

## Types and succession of SNF

### Sandy *Pinus sylvestris* var. *mongolica* Forest (SPSMF)

SPSMF mainly distributes at the eastern part of Hulunbeier Plateau, which is dunes in middle part of Haila'er River, and Yimin River (Honghua'erji), and Hui River watershed. The geographical range is about 47°-49° N, 119°-120° E. There are three pieces of SPSMF. (1) In dunes along the river in Cuogang-Wangong around, forest belt is about 13-14 km long, about 2 km wide. Some forest became flowing dunes due to human activities and overgrazing. (2) In Western Mountains and Northern Mountains of Hailar, which is a national forest park, there are 4 632 big trees, where about 1 000 trees are more than 100 years old. (3) In Honghua'erji, SPSMF is typical and the area is largest. The forest belt is about 150 km long, and 10-20 km wide. The forest area is 220 000 hm<sup>2</sup>, and timber accumulation is 11 180 m<sup>3</sup>. There are four kinds of SPSMF community type.

(1) *Carex spp*-*Populus spp*-*Betula spp*-*Pinus sylvestris* var. *mongolica* forest. It distributes in shade slope of dunes, and mainly composed of *Pinus sylvestris* var. *mongolica*, *Betula platyphylla*, *Populus davidiana*, and so on, tree height is 7-16 m, and canopy close degree is about 0.6. In shrub layer, main species are *Salix hsinganica*, *Rosa davurica*. In herb layer, *Carex spp* are the main species.

(2) *Thymus serpyllum*-*Pinus sylvestris* var. *mongolica* forest. It distributes in sunny slope and top of dunes. SPSMF here is old-growth forest, and canopy

close degree is about 0.4. In understorey, the main species is *Thymus serpyllum*.

(3) *Carex spp*-*Pinus sylvestris* var. *mongolica* forest. It distributes in low-lying land as a typical community type. Trees averages 12 m in height, with a mean DBH of 22 cm, and canopy close degree is 0.6. The main species is *Malus baccata* in shrub layer, and *Carex pediformis* in herb layer. Seedlings density is 115 000 trees/hm<sup>2</sup>.

(4) *Grass*-*Pinus sylvestris* var. *mongolica* forest. This type of forest distributes in flat sandy land. It is similar with montane *Pinus sylvestris* var. *sylvestris* forest, This pure forest averages about 46 years in tree age, with a mean DBH of 20.1 cm, tree height of 18 m and canopy close degree of 0.7-0.8. In shrub layer, *Spiraea spp* are main species. In herb layer, there are *Maianthemum bifolium*, *Polygonatum humile*, *Sanguisorba officinalis*, *Carex spp*, and so on.

SPSMF is stable community type. If it is destroyed by human activities, its succession will be as follows (Fig. 2).

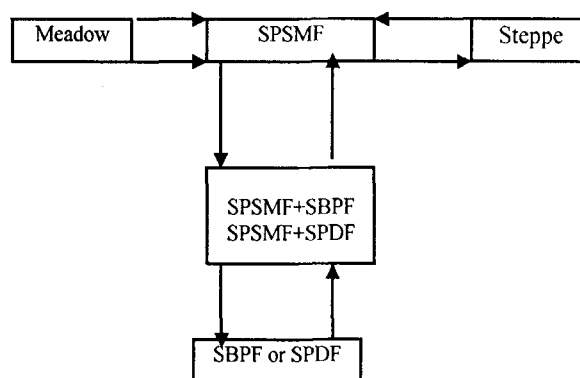


Fig. 2. Succession of SPSMF

If human destruction stops, the forest can develop succession under natural conditions, and forms climax vegetation. But, the time may be very long, somewhat several generations. Once the forest became arid steppe (*Thymus serpyllum* shrub), the vegetation will be difficult to restore to be forest vegetation.

### Sandy *Picea mongolica* Forest (SPMF)

SPMF mainly distributes in Baiyinaobao Natural Reserve, Inner Mongolia Autonomous Region of China, at the eastern edge of Hunshandake Desert. Long axis direction of dunes is from northwest to southeast. Landforms have top of dunes, low land among dunes, shade slope and sunny slope of dunes. SPMF mainly distributes in shade slope of dunes and low land, and the area of forest is about 1 967 hm<sup>2</sup>. SPMF is very special forest ecosystem in Europe-Asia continent. But it is different from mon-

tane *Picea* spp forest (Zou et al. 1998).

Firstly, as to community appearance, there are no *Leucodon pedulus*, *Usnea lougissina*, *Neckera pennata*, and so on in the forest because of drought climate in the edge of Hunshandake Desert, which is appearance landscape of typical montane dark coniferous forest. Secondly, as to community composition, SPMF is almost a pure forest. Sometimes, there are few *Betula platyphylla* and *Ulmus pumila*. However, in montane *Picea* spp forest, there are some *Abies* spp, *Acer* spp, *Sorbus* spp, and so on. Tree height in tree layer is 15-17 m. Under forest, there are few species, no pteridophyta, no scantentes. However, moss develops very well. There are many steppe compositions. This is different in dark coniferous forest. Thirdly, as to community structure, SPMF is simple, which can be divided into three layers, tree layer, herb layer, and moss layer. In slope of dunes, there is significant difference in water content of soil, which leads to variation of SPMF horizontal structure, and form obvious patches. The characteristic is rare in montane dark coniferous forest in China. Fourthly, as to ecological factors, factor limiting distribution and development of SPMF is water (moisture), but that limiting montane *Picea* spp forest is temperature. Therefore, prominent characteristic of montane *Picea* spp forest is cold and wet, but that of SPMF is cold and drought (Xu et al. 1993).

There are four kinds of community types of SPMF.

(1) Moss-*Carex* spp--sandy *Picea mongolica* forest (MCSPMF). It is typical SPMF, which distributes in shade and semi-shade slopes of dunes, and low land, with 1 300-1 450 m altitude. As to appearance, it can be divided into tree layer, herb layer, and moss layer. In tree layer, canopy close degree is 0.6-0.8, mean tree height 12 m, mean DBH 22 cm, tree age about 100 a, and population density is 300 trees/hm<sup>2</sup>. The forest is almost pure forest, only mixed with some *Betula platyphylla* and *Ulmus pumila*. The main species in herb layer is *Carex lanceolata*. Moss layer develops very well, and it is about 7-10 cm thick. But there are few species, such as *Phytidium rugosum*, *Phytidiadelpls trguetrus*, and so on.

(2) Herb-grass-sandy *Picea mongolica* forest (HGSPMF). This type of forest distributes at top of stable dunes, dry in the forest, and water content of soil is 2%-4%. *Picea mongolica* is the only tree species in this community type. Its mean tree height is 16 m, mean DBH 32 cm, and population density is 50 trees/hm<sup>2</sup>. It exists in 40-70 individuals patch. Canopy close degree is 0.2-0.3. Herb layer and moss layer distribute unevenly. In the southern direction of tree, herb species grow well, and in the northern direction of tree, there are many shade enduring species and moss, and distribute in semi-oval shape.

(3) Grass-*Betula platyphylla*-*Picea mongolica*

mixed forest. Tree species is composed of 70% *Picea mongolica* and 30% *Betula platyphylla*, and canopy close degree is 0.3-0.7. Tree layer can be divided into two sub-layers. The first sub-layer is 14-17 m high, composed of *Picea mongolica*. The second sub-layer is 7-10 m high, composed of *Betula platyphylla* and *Picea mongolica* seedlings.

(4) *Picea mongolica* forest along the river. It distributes along the river. Tree height is 16-18 m, DBH is 36-40 cm, and canopy close degree is 0.4-0.7. The forest is mixed with *Betula* spp and *Salix* spp.

Community succession of SPMF develops with fixation of sandy land and degeneration degree in two ways. (1) Progressive succession: which is from sandy pioneer community stage to rhizome-herb-grass community stage, then to *Picea mongolica* forest stage with variation of environmental conditions. There are two ways of succession due to differentiation of landform. The first is from rhizome stage to shrub stage and to moss--*Carex* spp--*Picea mongolica* forest in shade slope and semi-shade slope of dunes (Fig. 3). The second way is from rhizome stage to shrub stage and to herb--grass--*Picea mongolica* forest stage in sunny slope and top of dunes. (2) Regressive succession: It develops into different secondary vegetation types after SPMF is destroyed (Fig. 4). There are two ways

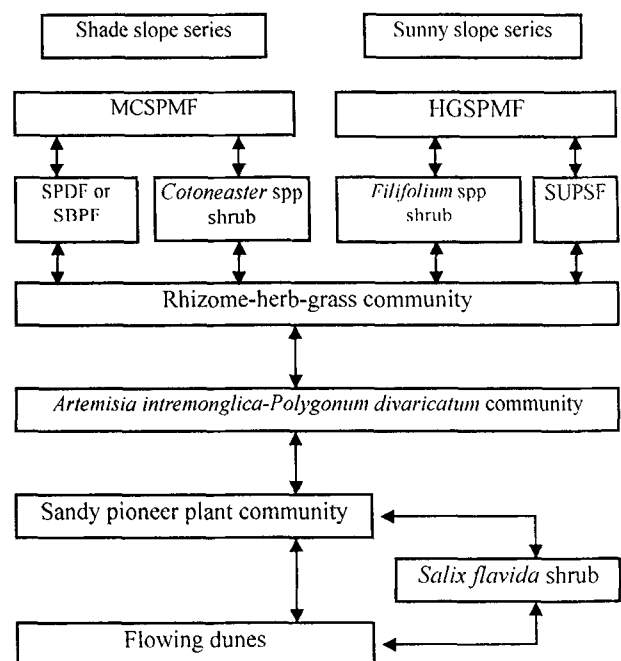


Fig. 3. Progressive succession of SPMF

of succession. The first is from *Picea mongolica* forest to *Populus* spp-*Betula* spp forest to shrub stage, and then to steppe in shade slope and top of dunes. The second way is from *Picea mongolica* forest to

steppe, then to flowing dunes in shade slope of dunes due to intensive human activities (Zou *et al.* 1999).

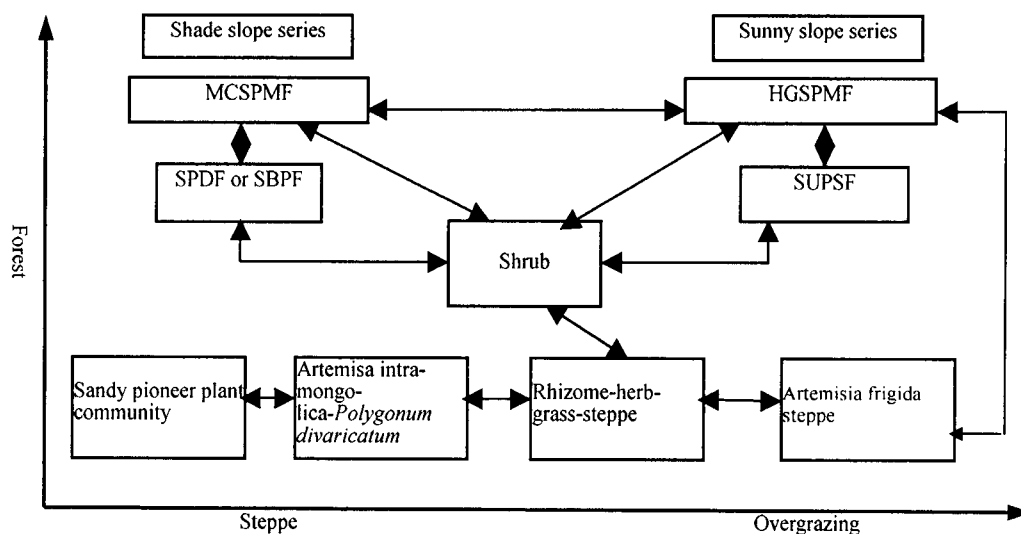


Fig. 4. Regressive succession of SPMF

#### Sandy *Pinus tabulaeformis* Forest (SPTF)

SPTF mainly distributes at stable dunes in the eastern edge of Hunshandake Desert, Inner Mongolia, and sandy hill in Songshushan, Huanggangliang, and Dajuzi Mountains. Here is the most northern border of SPTF in China. There are about 200 hm<sup>2</sup> SPTF in Songshushan Mountains, Wengniute County of Inner Mongolia Autonomous Region, tree age is 40-60 years, and mean tree height is about 7 m. There are four kinds of SPTF. (1) sandy *Ostryopsis davidiana*--*Pinus tabulaeformis* forest, (2) sandy *Prunus sibirica*--*Pinus tabulaeformis* forest, (3) sandy *Acer mono*--*Pinus tabulaeformis* forest, (4) sandy *Quercus mongolica*--*Pinus tabulaeformis* forest. Succession of SPTF is simple (Fig. 5). But in shade slopes of dunes, vegetation forms sandy *Populus davidiana* or *Betula platyphylla*--*Pinus tabulaeformis* forest, then becomes *Populus davidiana* or *Betula platyphylla* forest, or *Ostryopsis davidiana* shrub.

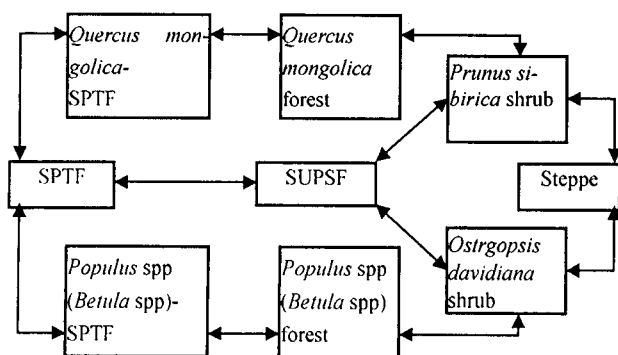


Fig. 5. Succession of SPTF

#### Conservation value and strategy of SNF

##### Conservation significance and value of SNF

SNF mainly distributes in Hulunbeier, Kerqin and Hunshandake sandy Lands in the northern part of China. Here is pastoral and merchandise food base. Therefore, conservation of existing sandy forests has important significance for controlling desertification, ameliorating ecological environment, decreasing sand blown in some cities, such as Beijing in North China, Shenyang in Northeast China.

SNF is very special forest ecosystems in terrestrial ecosystems. The main edificators are *Picea mongolica*, *Pinus sylvestris* var. *mongolica*, *Pinus tabulaeformis*, and so on, which are endemic or endangered species in China. Conservation for these forests is beneficial to understand plant evolution, evolve, paleoclimate, and paleogeology.

SNF is a natural gene pool for forestation in the northern part of China. According to selective theory of forestation species, SNF takes on the assignment for "Three North Protection Forest System" construction. According to statistical data, in the recent four years, seeds production of sandy *Pinus sylvestris* var. *mongolica* is about 210 000 kg in Honghuaerji, and seeds yield of sandy *Picea mongolica* is about 110 000 kg in Baiyinaobao, which supply seeds for more than 200 counties in China. Therefore, conservation existing SNF, improvement seeds yield, have important practical value (Xu and Zou 1998).

#### Measures should be taken for conserving SNF

(1) Intensifying ecological construction and man-

agement of the reserve. In order to protect SNF, some natural reserves were established, such as Daqinggou Sandy Broad-leaved Natural Reserve, Baiyinaobao Sandy *Picea mongolica* Forest Natural Reserve, Hailaer Sandy *Pinus sylvestris* var. *mongolica* Forest Park, Honghua'erji Sandy *Pinus sylvestris* var. *mongolica* Forest Natural Reserve, and Songshushan Mountains Sandy *Pinus tabulaeformis* Forest Natural Reserve.

(2) Intensifying fire control, stopping fire. Forest fire is important cause for destroying SNF. Two serious fires in 1952 and 1960 in Baiyinaobao destroyed 70% of SPMF. The fire in 1987 in Daxing'an Mountains destroyed most montane *Pinus sylvestris* var. *sylvestris* forest (Xu et al. 1998).

(3) Intensifying forest insect pest control. Forest insects are "non smoking fire". According to our research, in *Picea mongolica* forest, *Cephalicia abietis*, *Acantholyda peyingaobaoa*, *Gilpinia baiyinaobaoa*, *Ips duplicatus*, *Ips typographus*, and *Pseudotsugoides strobilellus*, and so on are very rampant every year. We should control the insect population in order to protect SNF.

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